Apparent motion of the ICRF sources

M. V. Sazhin[a]*, M.N. Siverskiy[b]†, V.E. Zharov[a]‡, V.N. Sementsov[a]§, O.S. Sazhina[a]¶

[a] *Sternberg Astronomical Institute of Lomonosov Moscow State University (SAI MSU)*
119992 Moscow, Universitetskiy pr. 13

[b] *Physical Department of Lomonosov Moscow State University (MSU)*
119991 Moscow, Leninskie Gory 1, build. 2

Abstract

What is the ICRF?

The modern International Celestial Reference System (ICRS) is based on the positions of specially selected compact extragalactic radio sources (quasars, active galactic nuclei (AGN), and blazars). The system axes are concerted with the axes of the FK5 system, and the system origin is located in the solar system barycenter, [1]. The physical realization of the ICRS is the International Celestial Reference Frame (ICRF), which is realized as catalog of 608 reference extragalactic radio sources. This is the set of precise coordinates of extragalactic radio sources (accuracy is better than $250\,mas$ in fact its tends to $50\,mas$), [2]. The proper motion of these radio sources is expected to be negligibly small because of their remoteness. Expected proper motion is $10nas/yr$.

The first adopted catalog contains 608 sources. The first realization of the ICRF (catalog) was constructed in 1995 by a reanalysis of the VLBI observations, [2]. 212 of these are defining sources providing a core of the ICRF, [2]. The estimated source position uncertainty for the "defining" sources is about $0.25\,mas$. 294 "candidate" sources have fewer observations. 102 "other" sources were added to make the ICRF denser. The radio source positions for the current ICRF realization were obtained from the analysis of observations from 1979 to mid 1995. Two extensions have been announced since 1995 covering observations at 1994 through 2002, [3]. Positions for 109 new radio sources were added to the list of the initial ICRF catalog. Distribution of these sources over the sky is presented on the fig.1

Analysis of apparent motion

As became evident after 30 years of observations many of the ICRF sources have significant apparent motion. To analyze this motion on can decompose this apparent velocity of the ICRF sources into a set of vector spherical harmonics, for instance, into E- and B-modes.

$$\vec{\mu}(\alpha,\delta) = \sum_{l,m} (a^E_{lm} \vec{Y^E_{lm}} + a^B_{lm} \vec{Y^B_{lm}}). \tag{1}$$

* **e-mail**: moimaitre@mail.ru
† **e-mail**: siverskiy.mihail@physics.msu.ru
‡ **e-mail**: vladzh2007@yandex.ru
§ **e-mail**: valera@sai.msu.ru
¶ **e-mail**: skoll@list.ru

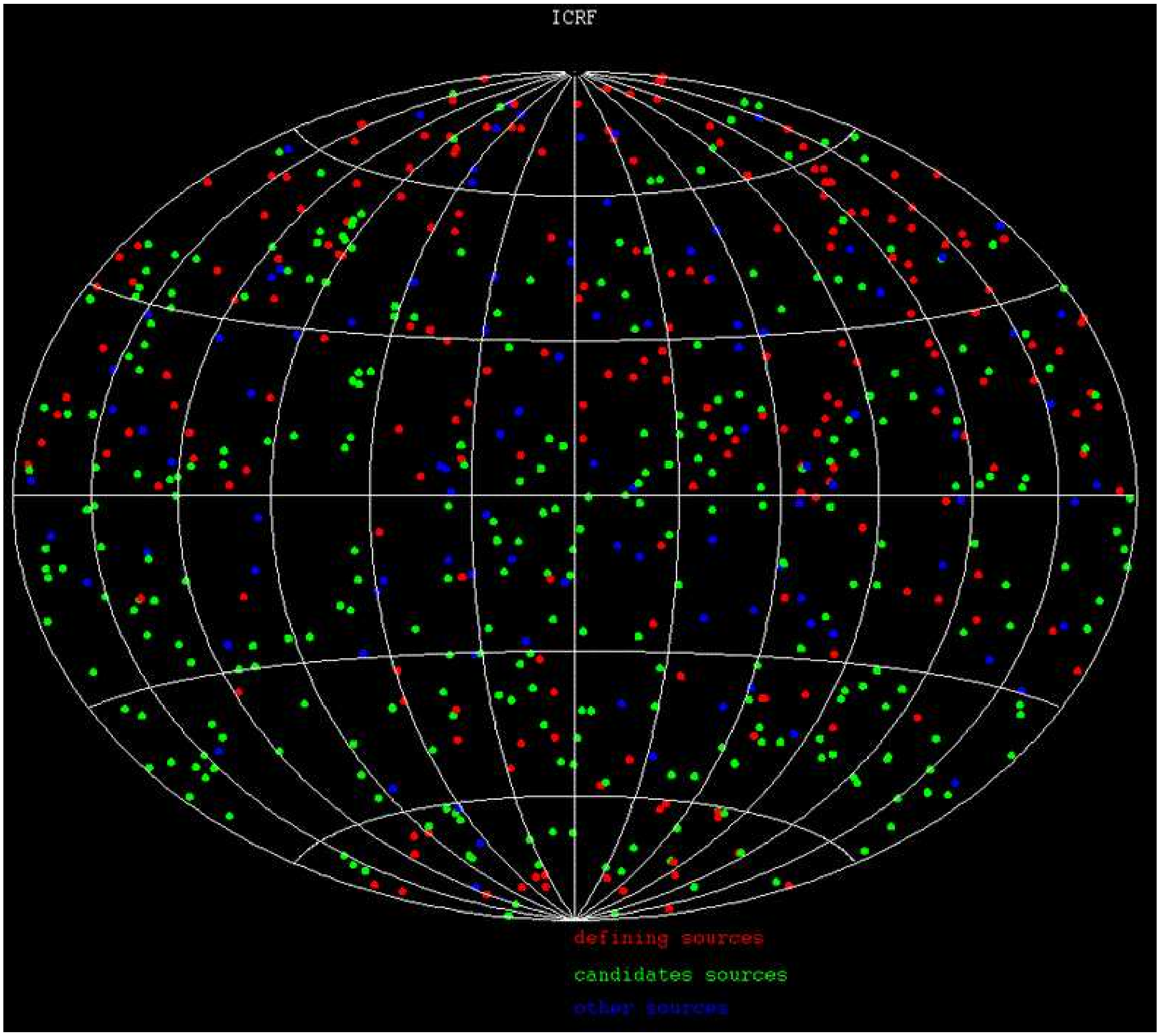

Figure 1: Distribution of the ICRF sources over the sky. Red dots represent defining sources, green dots represents candidate sources, and blue dots represent others sources in galactic coordinates.

Fig2 and fig3 represent vector field of apparent motion formed by E- and B-dipole harmonics. We have to mention also that dipole E-modes represent acceleration while B-mode represent global rotation.

There are several reasons for this apparent motion:

- Measurement errors
- Blandford-Rees effect (superluminal motion), [4]
- Accelerated of the Solar system [5]
- Nonstationary and achromatic space-time perturbations [6]

Measurement errors and Blandford-Rees effect produce almost "white spectrum" of the angular harmonics [7]. It is definitely not a case.

Here we analyze only dipole harmonics of the apparent motion. As a reason for dipole harmonic we consider accelerated motion of the Solar system with respect to the ICRF sources. Suppose that unity vector (reference vector) into direction of a extragalactic source is $\vec{K}$. If our

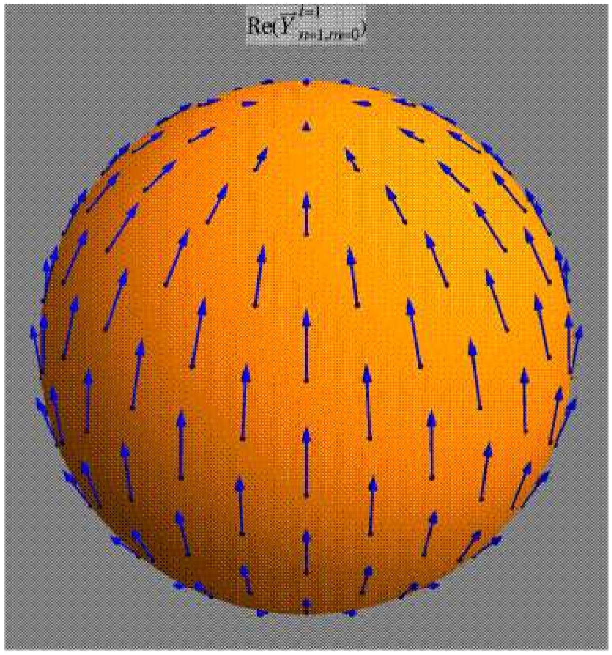

Figure 2: Distribution of the apparent velocity of the ICRF sources over the sky. This vector field was generated by E-mode $\vec{Y}^{l=1}_{m=0}$ harmonic. Acceleration vector is directed into the North pole of the local coordinate system.

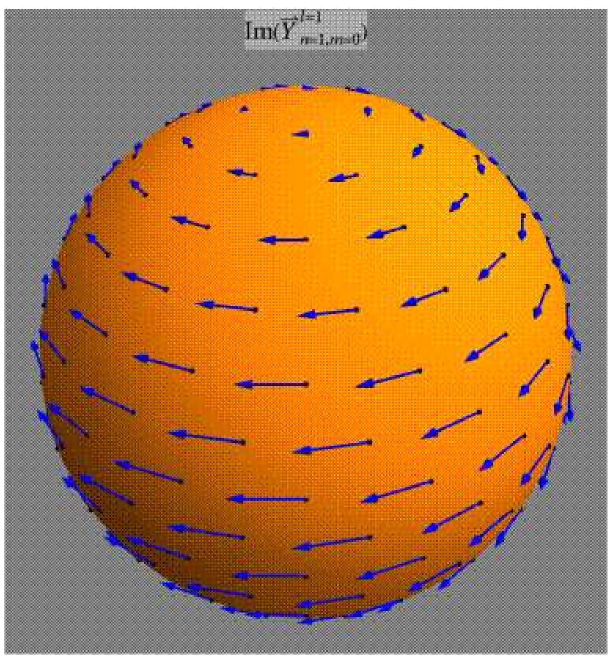

Figure 3: Distribution of the apparent velocity of the ICRF sources over the sky. This vector field was generated by B-mode $\vec{Y}^{l=1}_{m=0}$ harmonic. Acceleration vector is directed into the North pole of the local coordinate system.

solar system is moving with acceleration with respect to this source an relativistic aberration emerges:

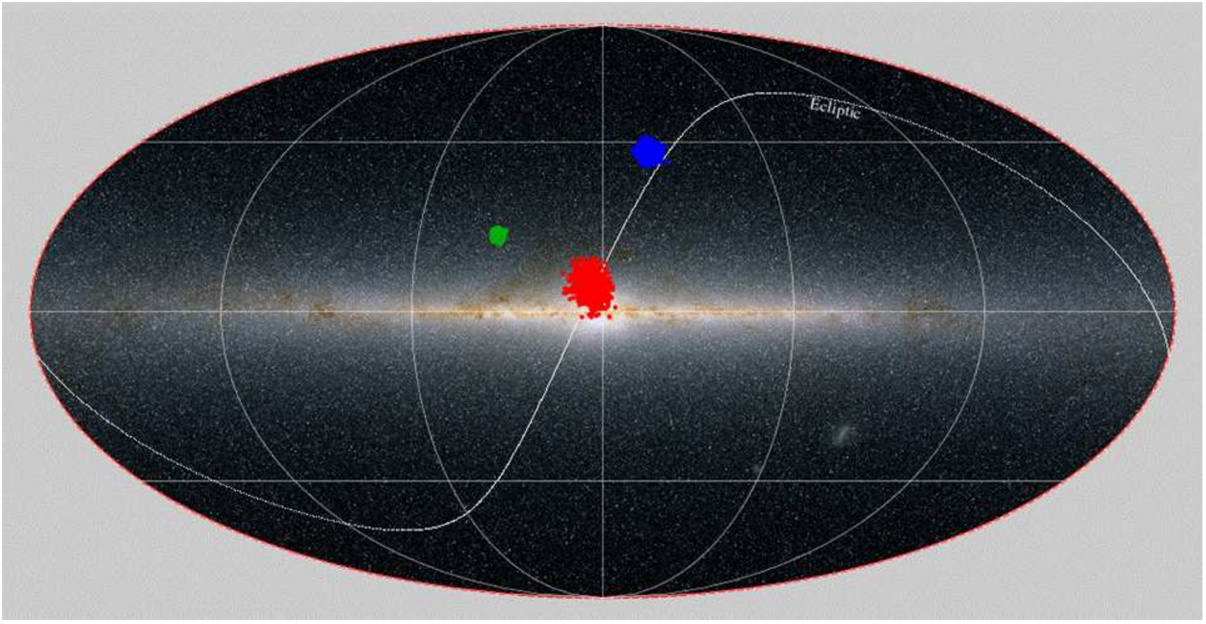

Figure 4: Direction of acceleration for three catalogs. Different colors correspond to different catalogs. Center of our Galaxy is in the center of map.

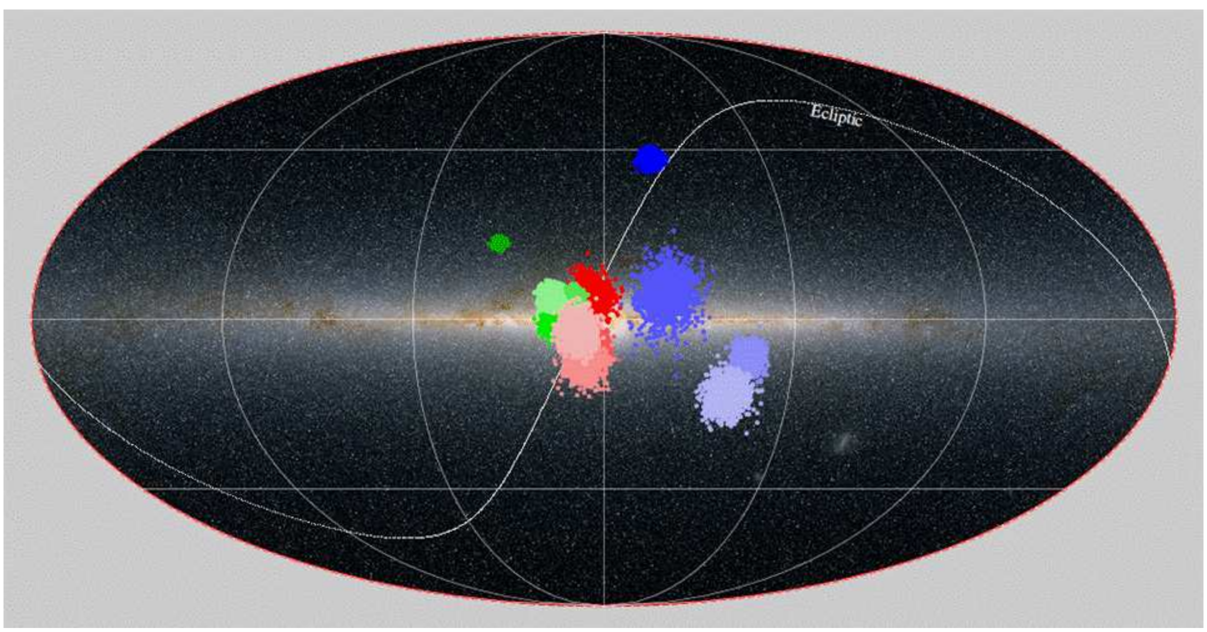

Figure 5: Direction of acceleration for three catalogs. Different colors correspond to different catalogs. Light to dark intensity of one color corresponds to different models. Center of our Galaxy is in the center of map.

$$\vec{k} = \vec{K} + \frac{1}{c}\vec{K} \times [\vec{V} \times \vec{K}] + \frac{1}{c}\vec{K} \times [\vec{A} \times \vec{K}](t - t_0), \tag{2}$$

here $\vec{k}$ is unity vector to apparent position, while $\vec{K}$ is reference vector. $\vec{A}$ is acceleration of the solar system with respect to the extragalactic source. Now $\vec{k}$ is linear function of time, therefore the derivative of $\vec{k}$ with respect to time emerges. This first derivative is apparent motion of the extragalactic source with respect to our local coordinate system:

$$\vec{\mu} = \frac{1}{c}\vec{A} = \frac{1}{c}\frac{V^2}{R}\vec{n}. \tag{3}$$

The value μ has been estimated as $\mu = 4\mu$as/year, [5], based on modern model of our Galaxy.

Here $\vec{K}$ and $\vec{k}$ are proper and apparent positions of a source respectively.

$$\vec{K} = (\sin\theta\cos\phi, \sin\theta\sin\phi, \cos\theta),$$

$$\vec{A} = (a_1, a_2, a_3),$$

$$\vec{\mu} = \frac{\partial\vec{k}}{\partial t} = \frac{1}{c}\vec{K} \times [\vec{A} \times \vec{K}].$$

In spherical basis $\{\vec{e_r}, \vec{e_\theta}, \vec{e_\phi}\}$.

$$\mu(\vec{\theta,\phi}) = \vec{e_\theta}(a_1\cos\theta\cos\phi + a_2\cos\theta\sin\phi - a_3\sin\theta) + \vec{e_\phi}(a_2\cos\phi - a_1\sin\phi).$$

Apparent motion μ represent dipole spherical harmonic.

$$\vec{\mu} = \sum_{l=1}^{\infty}\sum_{m=-l}^{m=l}(a^E_{lm}\vec{Y^E_{lm}} + a^B_{lm}\vec{Y^B_{lm}}). \tag{4}$$

And

$$a_1 = \Im(a^E_{1,1})\sqrt{\frac{3}{4\pi}}$$

$$a_2 = \Re(a^E_{1,1})\sqrt{\frac{3}{4\pi}}$$

$$a_3 = \Re(a^E_{1,0})\sqrt{\frac{3}{8\pi}}$$

Values of dipole harmonics of the ICRF sources apparent motion

We analyze three catalogs of apparent motion. Two catalogs were formed by O.Titov and one catalog was formed by V.Zharov. These catalogs were formed by different methods to avoid systematical errors. We evaluate amplitudes a^E_{lm} and a^B_{lm} by standard method. We considering the following models of velocity field distributions. At first we restrict with the dipole harmonic only ($l = 1$). The second model has two harmonics: dipole and quadrupole ($l = 1, 2$). The third model contains dipole, quadrupole, and octupole harmonics ($l = 1, 2, 3$). The last model contains 4 harmonics.

Value of secular apparent velocity measured is $\mu = 7 \pm 2\mu$as/year. This value coincides with result by O. Titov, [8], and is twice larger then expected from theoretical assumptions.

	catalog 1	catalog 2	catalog 3
$l = 1$	6.5 ± 0.3	16.3 ± 0.2	7.5 ± 0.2
$l = 1..2$	7.2 ± 0.3	12.5 ± 0.3	3.6 ± 0.3
$l = 1..3$	6.9 ± 0.3	13.8 ± 0.3	9.8 ± 0.3
$l = 1..4$	7.3 ± 0.4	13.3 ± 0.3	7.0 ± 0.3

Table 1: Here the values of dipole harmonic in different models and catalogs are listed. Numerical values are in units μas/year.

One of the possible explanation is than we are dealing with non-circular motion of Solar system inside our Galaxy. The second explanation is that there is a dark object in vicinity of the Solar system. Finally, this result could support MOND gravity for these scales (almost perfect match).

This work was partially supported by Russian Foundation for Basic Researches (project N 13-02-00184).

References

[1] Zharov V.E., Spherical Astronomy. *Fryasino, Vek-2, 478 p. (2006).*

[2] Ma C., Arias E.F., Eubanks T.M. et al. *AJ 116 516 (1998).*

[3] Fey, A.L., Boboltz, D.A., Gaume, R.A., Eubanks, T.M., & Johnston, K.J. 2001, *AJ, 121, 1741* ; Fey, A.L., Ma, C., Arias, E.F., et al. 2004, *AJ, 127, 3587*

[4] Begelman M.C., Blandford R.D., Rees M.J. *Rev. Mod. Phys. 56 255 (1984).*

[5] Kopeikin, S.M., & Makarov, V.V. 2006, *AJ, 131, 1471*

[6] Marakulin A.O., Sazhina O.S., Sazhin M.V., *JETP 141 6 (2012)*

[7] Sazhin M.V., Sazhina O.S., Marakulin A.O. *2011, Astronomy Reports, 55, 945*

[8] Titov, O., & Lambert, S. 2013, *Astronomy & Astrophysics, 559, AA95*